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UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

Association Internationale
d'Hydrologie Scientifique

SYMPOSIA DARCY
(Dijon, 20-26 septembre 1956)

subventionnés par l'UNESCO

TOME I. — EVAPORATION

Publication n⁰ 40 de l'Association Internationale d'Hydrologie

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COMMUNICATIONS RELATIVES A L'ÉVAPORATION

VAPORATION FROM THE WATER SURFACE OF A RESERVOIR

by

Charles F. LAPWORTH, B. Sc., M. I. C. E.

mmary

Daily measurements of rainfall and of water levels in a reservoir and an evaporation k near London have been taken from 1 July, 1955 to 30 June, 1956. Derived values of nthly totals of evaporation are given in the paper, with a corresponding theoretical imate based on meteorological data. Totals and extremes in mm are:

	Annual Total	Maximum Month		Minimum Month	
		Month	Total	Month	Total
eservoir	660	July	119	Dec.	10
nk	563	July	106	Feb.	2
eoretical	695	July	104	Dec.	13

Introduction

This paper records the first year's measurements of the evaporation loss from the ter surface of an open reservoir belonging to the Metropolitan Water Board at Kempton rk near London.

The reservoir is normally filled by pumping but for the duration of the measurements was set aside and not used for supply, so errors arising from the measurements of inflow d outflow are eliminated. Only two measurements are needed to obtain the evaporation s, namely water level and rainfall.

Particulars of Reservoir

The reservoir was constructed by excavating gravel within the area of the reservoir d forming this into a perimeter bank 10 to 30 feet above ground level and 5,460 feet 70 m) in length. The bank is made watertight by a wall of puddled clay in the centre the bank which is carried down in a trench through the overlying material into the London y which in this area is upwards of 200 feet in thickness. So far as is known the reservoir watertight, there being no leakage visible either on or near the banks. Before measurements re commenced, the inlet and outlet mains which are controlled by valves were inspected watertightness.

During the period under review the water level varied between about 6 and 7 feet below top of the bank, the average level being about 6.5 feet.

Particulars of the reservoir are as follows:

Position — Kempton Park.	12 miles S. W. of London Lat. 51° 25' N. Long. 0° 23' W.
Height of water surface at mean level	64.5 ft. O.D.
Area of water surface at mean level	41.5 acres (0.17 Km^2)
Max. depth of water surface at mean level	30.5 ft. (9.3 m)
Mean depth of water surface at mean level	19.5 ft. (6.0 m)

3. Water Level

The water level is continuously recorded on a chart by a float-operated water-level recorder. The scale of the charts, which are changed weekly, is 2/3 natural size. The level is measured in the outlet well of the reservoir which is connected to the reservoir by a pipe. A valve on the pipe is kept almost closed so as to damp down oscillations due to waves. At times of high wind there is oscillation of up to 1/4 inch; during normal conditions, the pen gives a smooth trace on the chart. The level given by the recorder is checked occasionally under still conditions against a hook gauge.

During February 1956, ice formed in the outlet well and daily readings were unreliable. An adjustment of +0.30 in. was made to the reading for March 1st but total fall for February and March was unaltered. As evaporation was small during that period, the adjusted reading is not likely to be seriously in error.

4. Rainfall

A rain gauge was sited at the Kempton Waterworks about 1/2 mile west of the reservoir. This gauge has been used for the determination of the rainfall on the reservoir area. The monthly values are given in Table 2.

There are other gauges at Hampton Waterworks about a mile to the south east, and at Hampton Sewerage Works just over a mile to the north east of the reservoir, and their records have been used to check the rainfall measurement on the reservoir.

For October 1955, the values of the Kempton gauge have been adjusted by —0.40 in. because of a local thunderstorm, to give the rainfall on the reservoir.

For the twelve months under review, the rainfall was considerably less than normal being about 71% of the annual average, the total for the twelve months being 16.13 inches This compares with a total of 16.26 inches for the mean of the three gauges.

5. Temperature

The temperature of the water in the reservoir has been taken at one point for each metre of depth in the reservoir at approximately monthly intervals.

During the summer months, the temperature decreased with depth, the range varying from 1° to 4° F. During the winter months, the temperature was generally uniform throughout The temperature at a depth of 3 metres is considered to give approximately the average temperature of the water in the reservoir. These values interpolated for the first of each month are given in Table 1.

TABLE 1
Mean Water Temperature

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
°F	62	68	68	60	50	45	42	37	33	43	52	60	63
°C	16.6	20.0	20.0	15.5	10.0	7.2	5.5	2.7	0.5	6.1	11.1	15.5	17.2

For the first two months of the record before temperature readings were started, dat for the nearby King George VI Reservoir were used. Later comparison of temperatures i the two reservoirs showed not more than 0.5°F difference between the two.

6. Evaporation

The figures in column 5 of Table 2 show the indicated monthly evaporation based upo water level and rainfall. Corrections are necessary for several reasons. The inner bank o the reservoir is covered with concrete slabs sloping towards the reservoir so that the reservoir receives rainfall from a larger area than the water surface. Though the width of the additional area varies with the water level in the reservoir, the actual variation was less than a foot and the average width of 20 feet may be used with sufficient accuracy. At this width, the additional area contributing rainfall to the reservoir is equal to 6% of the reservoir area. Some water is, however, lost by evaporation on the slabs before it reaches the reservoir. During the winter months not much was lost; in the summer months probably 50% was lost by evaporation from the slabs. To allow for the increased rainfall on the inner bank, the indicated evaporation losses have therefore been increased by the following amounts

Winter months — Oct.-March	5% rainfall.
Summer months — Apr.-Sept.	3% rainfall.

A second correction (Table 2, Column 7) takes into account the variations of water density arising from variations in water temperature (Table 1).

A third correction is made for bank storage (Table 2, Column 8). Water from the reservoir saturates the gravel portion of the bank as far as clay puddle wall. The water contained in the bank is not subject to evaporation, or only a very small amount close to the water surface. Changes of water level in the reservoir are therefore less than they would otherwise be owing to the balancing effect of the storage within the bank. The correction has been made according to the rise or fall in water level, assuming that the gravel has a porosity of 30% of the volume.

The observations, corrections, and the corrected estimate of evaporation are given in Table 2.

6. Meteorological data

Meteorological data are available for a station at Kew, about seven miles from the reservoir.

The air temperature, vapour pressure and wind speed are the means of hourly values. The wind speed as given in the table is measured at an effective height of 50 feet above ground level.

TABLE 3

Meteorological data for Kew
Lat. 51°. 28' N. Long. 0°-19'W.
18 ft. above sea level

1	2	3	4	5	6
Month	Mean Solar Radiation	Mean Air Temperature	Mean vapour pressure	Mean Duration of sunshine	Mean wind speed
	mw.hr./cm²/day	°C	mb.	Hrs/day	m/sec.
July '55	478	18.3	14.6	7.9	3.2
Aug.	373	18.7	15.5	6.4	2.8
Sept.	296	14.7	12.9	5.6	3.0
Oct.	158	9.7	9.8	3.6	2.9
Nov.	68	8.1	9.0	1.4	3.2
Dec.	48	7.0	8.5	1.5	4.0
Jan. '56	55	4.6	7.2	1.6	3.9
Feb.	103	0.1	4.6	2.2	4.15
Mar.	232	6.9	7.2	4.6	4.3
Apr.	305	7.5	7.0	4.9	3.7
May	491	13.3	9.7	8.3	3.6
June	379	14.2	11.7	4.9	3.9

TABLE 2

Monthly evaporation from the reservoir

1	2	3	4	5	6	7	8	9	10
					Corrections for				
Month	Water level at 1st of month above 64.0' O.D.	Fall in water level during month	Rainfall during month	Indicated Evaporation loss (Col. 3 + 4)	Rainfall on bank	Density of water	Bank storage	Corrected Evaporation (Col. 5 + 6 + 7 + 8)	Corrected Evaporation
	in.	in.	in.	in.	in.	in.	in.	in.	mm.
July '55	12.72	+3.84	0.65	4.49	+.02	+.14	+.07	4.72	119
Aug.	8.88	+3.00	0.90	3.90	+.03	0	+.05	3.98	101
Sept.	5.88	+1.50	1.91	3.41	+.06	—.18	+.03	3.32	85
Oct.	4.38	—0.42	2.57	2.15	+.13	—.16	—.01	2.11	54
Nov.	4.80	+0.05	1.10	1.15	+.06	—.04	0	1.17	30
Dec.	4.75	—1.55	1.91	0.36	+.10	—.02	—.03	0.41	10
Jan. '56	6.30	—3.20	3.54	0.34	+.18	0	—.06	0.46	12
Feb.	9.50	+0.55	0.17	0.72	+.01	—.02	+.01	0.72	18
Mar.	8.95	+0.30	0.48	0.78	+.02	0	+.01	0.81	20
Apr.	8.65	+0.80	1.04	1.84	+.03	+.08	+.01	1.96	50
May	7.85	+2.75	0.15	2.90	0	+.14	+.05	3.09	78
June	5.10	+1.40	1.71	3.11	+.05	+.07	+0.2	3.25	83
July	3.70								
Total		9.02	16.13	25.15	+0.69	+0.01	+0.15	26.00	660

7. Calculated evaporation

Penman (1) has given a method of calculating the evaporation from a water surface based upon weather data. The method depends upon a combination of the heat balance and aerodynamic approach. Based upon the weather data given in Table 3, the calculated evaporation from the reservoir for each month (after correction for heat storage) is given in Table 4. The total for the year is about 5% greater than the recorded evaporation from the reservoir.

TABLE 4

Calculated evaporation

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Year
In.	4.1	4.0	3.7	2.2	1.0	0.5	0.8	1.0	0.7	2.3	3.6	3.5	27.4
mm.	104	101	94	56	26	13	21	26	17	57	92	88	695

8. Evaporation Tank

An evaporation tank of British Meteorological Office pattern, six feet square and two feet deep was installed at the Kempton works about 1/2 mile from the reservoir. The tank is sunk into the ground to the level of a horizontal flange fixed three inches below the top of the tank. The water level was maintained at a level as nearly as possible between two and three inches from the top of the tank. The water was measured daily by means of a hook gauge set in a stilling chamber at the side of the tank. Rainfall was measured by the rain gauge close to the tank. Evaporation data for the twelve months are in Table 5.

TABLE 5

Monthly evaporation from the tank

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Year
In.	4.19	3.63	1.92	1.25	0.54	0.32	0.12	0.07	1.17	1.82	3.86	3.25	22.14
mm.	106	92	49	32	14	8	3	2	30	46	98	83	563

Except for two months in the spring, the evaporation from the tank was equal to or less than from the reservoir, the total for the year being 15% less.

Acknowledgements

The work has been undertaken by the Evaporation Sub-Committee of the Hydrological Research Group of the Institution of Water Engineers. Instruments have been provided by the British Meteorological Office. Readings have been taken by the Metropolitan Water Board.

Thanks are due to Dr. J. Glasspoole of the Meteorological Office for assistance with rainfall records and Dr. H. L. Penman of the Rothamsted Experimental Station, for the figures for calculated evaporation.

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THE APPLICATION OF RESEARCH ON EVAPORATION IN HYDROLOGY

by

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For the hydrologist the yield of water depends on precipitation and evapotranspiration. The latter depends in the first place on climate and weather, secondly on type of surface: water, bare soil, vegetation short or not short of water.

The hydrologist needs a simple method to estimate the quantity of water evaporating from a catchment area. In measuring precipitation (P) and run-off (R), only minor problems are involved. However, evapotranspiration for periods shorter than a year can not be estimated from the difference P — R, apart from special cases where the introduction of the «natural drainage period» (Penman and Schofield, 1941) enables the estimation of evapotranspiration for shorter period and for a vegetation. Non-weighable lysimeters (percolation gauges) do not give information on evapotranspiration in monthly periods, either.

Blaney and Criddle (1950), Thornthwaite (1948) and Penman (1948) developed convenient formulae to estimate from standard weather data, only, potential evapotranspiration (E_P), being evapotranspiration of a green surface never short of water. These formulae can be used to calculate even monthly evaporation for catchment areas. Van Wijk, De Vries and Van Duin (1953), and Van Wijk and De Vries (1954) showed that evapotranspiration (E_P) is in phase with radiation flux and not with temperature. For this reason Penman's calculation, where E_P mainly depends on radiation is to be preferred above the methods of Thornthwaite and of Blaney and Criddle, where E_P is based mainly on temperature.

Instead of calculating potential evapotranspiration, it is possible to determine it empirically by means of a tank with an infiltrated grass cover (Sanderson 1948). A standard evaporimeter may be used instead, provided the relation between the evaporation from the instrument (E_W) and E_P is known.

This approach of determining one basic factor (E_W or E_P) which is mainly of meteorological character, is a practical one. However, a set of conversion coefficients is needed for all those parts of a catchment area where vegetation is wholly or partly lacking, where vegetation is short of water, or vegetation may not be considered a grasslawn, because of plantspecies, state of ripening, roughness length, permeability for wind, reflexion coefficient, etc. For vegetations where water is limiting Penman gives two estimates: *a*) the quantity of water obtainable without restriction (the «root constant») and *b*) the velocity of withdrawal of the remaining water (Penman 1949). He also gives a coefficient to overcome the aerodynamical structure of fruityards (Penman 1952). All those estimates have a provisional character and must be replaced in due course by experimentally determined ones.

Makkink and Van Heemst (1956) using weighable lysimeters, showed for a grass vegetation on undisturbed claysoil, how that actual (limited) evapotranspiration depends on soil moisture tension and potential evaporation. It is likely that it depends for a great part on density and growth of the plant roots whether a crop will suffer from water shortage or not. The controversy concerning availability of soil moisture may result from not taking in account root development (Veihmeyer and Hendrickson 1955).

Möller's (1951) method of obtaining an overall figure for the evapotranspiration of an extensive area must also be mentioned. He calculated the evapotranspiration from a waterbalance sheet of the atmosphere. Variations in humidity are measured spectrographically and by pilot balloons. Precipitation is known, whereas advective transport of water in the air has to be zero or must be estimated in some way. Whether this method can be applied in hydrology is not known yet.

There are several other ways to determine evaporation of a surface. Most of them are not convenient for the hydrologist, because expensive instruments and too much work are needed.

In the first place there are the aerodynamic methods, based on turbulent vapour transport. Research at Lake Hefner (Oklahoma)(Harbeck and others, 1952) showed that the formulae of Sutton (1949) and of Sverdrup (1937) gave the best agreement with the waterbalance sheet data. Also Pasquill (1950) obtained a satisfactory agreement between observations and calculations after Prandtl's formula. In the Dutch Rottegatspolder the formula of Thornthwaite and Holzman, adapted according to the Businger's theory of stability (1954), s applied and the results are compared with those of the waterbalance sheet (Deij 1954).

Schmidt (1925) studied the vertical transport in the air and Swinbank (1951) measured the ever changing vertical component of the air velocity simultaneously with variations in water vapour density. This method seems to be promising for research work.

The heat balance sheet of the lower air layer provides another possibility to determine the evapotranspiration of a vegetation (Albrecht 1937, 1950); some data agree satisfactorily with data obtained with the «momentane» plantecological method, where loss of water is determined for short exposures of detached leaves or shoots (Berger-Landefeldt 1949). This method (Huber 1927, Stocker 1929, Pisek and Cartellieri 1932, Pfleiderer 1933) presents another experimental way to give all necessary coefficients for various vegetations, although critical application, especially concerning the conversion towards the unity of soil area, is necessary.

Also soil scientists, determining moisture content in the root layer, may contribute additional coefficients. Application of the electrical resistance method (Bouyoucos and Mick 1940) or the gravimetric method provided many crop constants on evapotranspiration Blaney and Criddle 1950).

Finally, those who are working with weighable or with recording lysimeters may find some coefficients for kind of crop and for conditions of water shortage (Harrold and Dreibelbis 1951, Harrold 1955, Ramsauer 1956). These installations can be used, too, for checking basic formulae (Makkink 1955). Lysimeters planted with forest, though not weighable, are of great value for the study of interception (1) (Ovington (2), Wind 1955).

Most ways of determining or calculating evapotranspiration are not yet perfect, discrepancy between experiment and theory being often intolerably high. This is partly due to experimental errors, partly to the difficulty to develop formulae completely covering the complicated phenomena of turbulence and instability of the air (Harbeck and others 1952, Berger-Landefeldt 1953, Deij and others, 1956).

The investigations to be carried out in future must deal with improving of methods and formulae and with various aerodynamical exchange coefficients (Penman 1956).

As pointed out above we must collect from literature and experiment an arsenal of specific coefficients in addition to calculated or to the determined values of E_W or E_P.

Some attention has to be paid also to the choice of devices : evaporimeter and lysimeters Harbeck and others, 1952, Baumbach 1952, Koriba 1943, Venema and De Vries 1954, Briggs and Shantz 1917, Boss 1952, Schubach 1952). If in future investigations on evaporation on an international base will occur, a discussion on instrumentation seems to be necessary.

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SUR L'INDICE D'EVAPORATION DU BASSIN VERSANT ALPIN DE MATTMARK

par

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H. Keller a reconnu déjà en 1914 (8) * l'influence prépondérante de la température sur l'évapotranspiration et constaté que lorsque les précipitations augmentent, l'évapotranspiration se rapproche d'une valeur limite dépendant de la température. Wundt (16,18) a élargi les études fondamentales de Keller et a établi, sur la base de l'observation de 220 bassins versants, des diagrammes avec la relation entre précipitation et débit, le paramètre température variant ent —5°C et +25°C. Lütschg (10) a étudié l'influence de l'altitude moyenne sur l'évapotranspiration de quelques bassins alpins. Les quelques points trouvés sont plus ou moins alignés sur une droite dans le diagramme évapotranspiration/altitude. Il a constaté en accord avec Keller et Wundt, une diminution de l'évapotranspiration avec l'augmentation de l'altitude, correspondant à une diminution de la température moyenne.

Dans toutes ces recherches on a constaté une dispersion appréciable entre les points observés et les relations théoriques. Cette dispersion nous rend attentifs aux caractéristiques particulières des bassins qui peuvent expliquer les écarts. Sans vouloir entrer dans le détail des facteurs divers : météorologiques, biologiques, pédologiques et géologiques qui peuvent influencer l'évapotranspiration nous ne ferons ici que donner le résultat de mesures de l'évapotranspiration de la haute Vallée de Saas (Mattmark) portant sur une période du bilan de 14 ans et les comparer aux résultats de Wundt et Lütschg.

Les eaux de la haute Vallée de Saas sont drainées à la station de jauge de Zermeiggern (1726 m.s.m.). Le bassin versant de 65.25 Km^2 est situé à la latitude de 46.0° N et à la longitude de 5.6° E. La vallée principale s'étend sur presque 10 km du sud au nord; le point culminant est situé à l'altitude de 4198.9 m.s.m. alors que l'altitude moyenne est de 2850 m.s.m. qui correspond pour notre période de référence 1932-1946 à une température moyenne d'environ —3°C. La plupart des glaciers se trouvent sur le versant gauche du vallon principal et sont exposés dans le secteur du Nord à l'Est et couvrent une superficie de 25.57 km^2 (en 1932), soit 39.2% du bassin entier; 25.0 km^2 sont constitués par des rochers et des éboulis; il n'y a que 0.7 km^2 de forêts et le reste d'environ 14 km^2 est recouvert d'alpages. Le bassin versant peut être considéré comme étanche, de sorte que les partages des eaux orographiques et hydrographiques sont identiques. On trouvera des indications détaillées sur cette région dans la monographie de Lütschg (9).

Notre calcul du bilan pour les 14 ans 1932-1946 se base sur les observations suivantes :

a) *Précipitations.* Sur la base des mesures des précipitations de 12 totalisateurs on a dessiné les isohyètes qui ont été planimétrées. Il est résulté une moyenne annuelle du bassin de $N = 1914$ mm.

b) *Variations de volume des glaciers.* L'institut photogrammétrique de l'EPF (M. Zeller) a procédé en automne 1932 et 1946 à un relevé photogrammétrique terrestre à partir de 22 bases. L'élaboration des résultats s'est faite sur une carte au 1 : 10 000 avec une équidistance de 10 m. Le planimétrage des deux relevés à l'aide d'une méthode décrite par Lütschg (10) a conduit à une réduction annuelle moyenne de volume de $4.24 \cdot 10^6$ m^3, qui répartie sur le bassin entier, en tenant compte d'un poids spécifique de 0.9 t/m^3 correspond à une lame d'eau $(R\text{-}B) = 58$ mm.

c) *Débit.* Le Service fédéral des Eaux à Berne enregistre les niveaux d'eau de la Visp de Saas à la station limnigraphique de Zermeiggern (15). Chaque année la relation débit/niveau a été contrôlée plusieurs fois par des jaugeages. Les mesures donnent une moyenne annuelle de $A = 1628$ mm.

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* Voir bibliographie à la fin du travail.

L'équation du bilan donne une évaporation moyenne de

$$V = 1914 + 58 - 1628 = 344\ mm/an = V$$

Les diagrammes de Wundt donnent pour N = 1914 mm et $t = -3$°C une valeur d'environ 210 mm; la relation linéaire de Lütschg conduit pour H_m = 2850 m.s.m. à 247 mm.

Pour le bassin versant de Zermeiggern, Lütschg a observé la différence entre précipitation et débit et trouvé 428 mm pour la période 1929-1939 et 288 mm pour la période 1922-1942. D'après les observations au Glacier d'Aletsch on peut admettre que pendant les deux périodes les glaciers ont diminué de masse de sorte que les valeurs de l'évaporation spécialement pour la région de Mattmark sont supérieures à celles que donnent la droite de régression selon Lütschg. Notre estimation de la diminution de la masse glaciaire conduit pour les deux périodes à une évaporation annuelle moyenne de 438 mm, resp. 334 mm.

Il n'est guère possible, sans étude spéciale poussée, d'estimer la précision du résultat de notre bilan. Cependant l'évapotranspiration ne saurait être en réalité inférieure à 300 mm.

La relation linéaire de Lütschg a été établie sur la base d'observations dans des bassins des Préalpes avec une maigre végétation, peu de forêts et peu de glaciers. Il semblerait possible que l'extrapolation de cette relation conduise à des résultats erronnés aussi bien pour le Plateau suisse avec sa culture intense du sol et de la forêt (2,3,4) que pour les hautes altitudes avec forte glaciation. On peut s'imaginer que la végétation conduise à des valeurs plus élevées de l'évapotranspiration et que d'autre part les glaciers et névés de 3000 à 4000 m augmentant sensiblement l'évaporation (1,6).

Les divers essais de mesurer l'évaporation de superficies de neige ont conduit à des résultats assez peu concordants (1,6,11,12); il y a probablement des raisons physiques de ce désaccord.

Il n'est pas impossible que pour les conditions alpines il ait une altitude correspondant à un minimum d'évaporation, la végétation dans les régions basses et la glaciation dans les régions hautes provoquant une augmentation de l'évaporation.

En se basant sur les expériences déjà faites, les hommes de science de chaque région devraient concentrer leurs moyens essentiellement sur un bassin versant. Il faudrait y appliquer en même temps les différentes méthodes, soit celle du bilan en examinant l'exactitude des observations, soit les méthodes physiques qui se prêtent à éclaircir le mécanisme de l'évapotranspiration. Cette collaboration permettrait de comparer et de contrôler mutuellement les résultats obtenus par les différentes études.

Summary

In the 39% glaciated basin of Mattmark (Swiss Alps) the water balance in the total area of 65.25 km² has been determined for the period from 1932 to 1946. The mean annuel precipitation was found to be 1914 mm, the loss of the glaciers 58 mm of water (calculated for the glaciated plus the non-glaciated areas), and the run-off 1628 mm. The evapotranspiration is therefore 344 mm. The mean elevation being 2850 m and the mean annual temperature being —3°C, this value is considerably higher than what would be expected from the work of Lütschg or Wundt. The question arises therefore whether in highly glaciated areas the evaporation is not increasing rather than decreasing with altitude.

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RESEARCH ON EVAPORATION AND EVAPOTRANSPIRATION IN THE UNITED STATES

by

Ray K. LINSLEY, Harry F. BLANEY, G. Earl HARBECK, and Max A. KOHLER

The recent years have seen a considerable resurgence of research on evaporation in the United States. The class A evaporation station continues to be the most widely used basis for evaporation estimates, and about 310 class A stations are operated by the Weather Bureau in the United States and its territories. The limitations of pan data, ajusted by an average coefficient, as a measure of lake evaporation are, however, well recognized. Extensive studies of alternative techniques such as the energy balance method and the mass transfer method have, therefore, been conducted. Research on the design of evaporation pans and the use of supplemental data to aid in the quantitative interpretation of pan observations is also underway. The Weather Bureau hopes ultimately to equip all class A pans with instruments for measuring pan water temperature.

The first of the recent research projects was the joint venture of the Bureau of Reclamation, Geological Survey, U. S. Navy, and Weather Bureau at Lake Hefner (1), Oklahoma. Measurements of evaporation based on a water budget for the lake were compared with estimates determined by use of various mass transfer equations and the energy budget method. Observations from class A pans and three types of sunken pans were also compared with the water budget data. As a result of this project an empirical mass transfer equation was developed which is believed to be applicable to other lakes. A considerable amount of information on radiation exchange, transfer of sensible heat, and other facts of the evaporation problem was also gained from the project, as well as experience in instrumentation. At Lake Hefner, the ratio of annual class A pan evaporation to lake evaporation was found to be 0.7, but monthly ratios varied widely because of heat storage in the lake. A relation for computing daily pan evaporation from solar radiation, air temperature, dewpoint, and wind was developed (2). Field work at Lake Hefner was accompanied by model test in a wind tunnel (3).

Using instrumentation and methods developed and tested at Lake Hefner, evaporation from Lake Mead during the 1953 water year (4) was found to be 875,000 acre-feet (85.6 inches). The Lake Mead investigations point up particularly the importance of the energy advection to the lake. The annual advection to Lake Mead is estimated to be the equivalent of about one foot of evaporation, although about half of the advected energy was dissipated through back radiation and sensible heat transfer. Similarly the transfer of heat through the walls of evaporation pans is a significant factor in determining the pan coefficients. A basis for estimating the coefficient from observations of wind movement and air and water temperature is available (2). The results obtained using the energy budget, empirical mass-transfer equation, and pan evaporation data for Lake Mead were in excellent agreement.

Continuation of the work initiated at Lake Hefner is underway at Felt Lake, California, through a cooperative agreement between the Weather Bureau and Stanford University with some of the instrumentation supplied by the Bureau of Reclamation and the Geological Survey.

In cooperation with the Texas Board of Water Engineers, the Geological Survey is conducting a study at Lake Colorado City, Texas, to determine the effect of addition of heat from a power plant on the thermal structure of, and evaporation from, the reservoir from various types of pans at its observatory at Silver Hill, Md. A large sunken pan (15 ft. diameter and 2 ft. deep) is being operated in the hope that it will simulate a shallow lake. Tests of the effect of non-standard operational procedures and of the effect of various metals for the pan are also being made.

In 1909 and 1910 an elaborate series of observations were made at the Salton Sea in southern California. The data collected were never published and were only partly processed hough tentative results were published (5). The original records are now being reevaluated the hope that they will provide additional verification of the results of recent experiments. nsiderable interest has also been exhibited in the probable level at which the Alton Sea l stabilize (6).

In cooperation with the Bureau of Reclamation, measurements of solar and atmospheric liation are being made at Granby Reservoir in Colorado, which is at an altitude of 00 feet. Evaporation from the reservoir is determined using the energy-budget method. idies of solar and atmospheric radiation and evaporation are being made also at a ter-supply reservoir on the south slope of Pikes Peak in Colorado at an altitude of 900 feet. The data obtained at these two high-altitude reservoirs should provide ch-needed information concerning the effect of altitude upon evaporation.

Studies of evaporation at high altitudes (7) in the Sierra Nevada of California are being ntinued cooperatively by the United States Department of Agriculture and the Southern lifornia Edison Company. Station elevations range up to 9200 feet above sea level. ney (8) has also studied the evaporation from Silver Lake in the Mojave Desert of lifornia. This lake basin was filled by a flood and subsequently emptied by evaporation hout surface inflow or outflow. Seepage losses are believed to have been negligible. A fficient of 0.6 for the class A pan was found in this instance. In 1955 the Department of riculture in cooperation with California State Division of Water Resources compiled and blished monthly records of evaporation for some 65 stations in California.

Much interest is currently being given to the possibility of suppresing evaporation m reservoirs. Various types of monomolecular films are under laboratory test at the ithwest Research Institute in Texas. The Bureau of Reclamation is studying the biological ects of such films on a small fishing pond in Oklahoma, while the Geological Survey aking a comparative study of evaporation from a small stock-water reservoir, with and hout the evaporation suppresing film. The Weather Bureau plans similar studies on pans Silver Hill and Stanford University.

Estimates of evapotranspiration in the United States are now generally based on formulas zing climatological data. The Blaney-Criddle and Lowry-Johnson formulas are probably st extensively used. Mr. Blaney has also applied his formula to the computation of poration. At Waynesville, N. C., the evapotranspiration from soil-filled gasoline drums s measured and compared with values computed from Penman's and Thornethwaite's mulas. The state of California is employing spherical, ceramic atmometers (Livingstone) ndices of evapotranspiration using a technique developed by Veihmeyer at the University California.

A research group at Johns Hopkins University has been studying the possibility of mates of evapotranspiration from continents or other large areas through analysis of atmospheric moisture balance (12). At Johns Hopkins (14) and Texas A & M College.work tinues on the measurement of the flux of water vapor from the ground by means of surements at two or more levels above the ground. There still exists the need for much re research before this mass transfer approach to the estimation of evapotranspiration omes a really practicable solution. A considerable field for research into the physiology transpiration, the effect of soil moisture (14), and soil moisture movement on potranspiration still remains.

It is the opinion of the American National Committee that a symposium on Evaporation l Evapotranspiration should be included in the program for the next General Assembly Toronto. These phenomena are major factors in the hydrologic cycle and of vital impor- ce in many fields of applied hydrology. Recent experimental work has given us a far better lerstanding of the quantitative mechanisms involved than has heretofore been available l a symposium dealing with this work would seem to offer much of value to the field scientific hydrology. In order to plan such a symposium we suggest the creation of a mmittee on Evaporation and Evapotranspiration and charged with the responsibility of nning and organizing a symposium for the Toronto Assembly. Subsequent plans for the mmittee would be developed at the Toronto meeting.

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EVAPORATION AND EVAPOTRANSPIRATION STUDIES UNITED STATES DEPARTMENT OF AGRICULTURE IN THE PACIFIC SOUTHWEST

by

Harry F. BLANEY

The storage of stream flow from mountain watersheds in reservoirs has made possible development of much of the irrigated agriculture in Western United States. These reser-rs help to prevent floods, conserve a water supply that otherwise might be wasted, and ke possible the production of power. The importance of a knowledge of water lost through poration and evapotranspiration to the efficient design and later operation of the works olved in a water-supply project has long been recognized by engineers.

Some of the studies being conducted on evaporation and evapotranspiration in the ific Southwest portion of the United States by the Department of Agriculture are as ows :

ricultural Research Service

There are very few instances where evaporation can be measured directly from lakes reservoirs because of the unknown elements of supply; such as, losses of water entering leaving the reservoir. Thus, research studies have been necessary to determine the tionships existing between evaporation from standard pans and climatological data, ich are measurable, and from lakes and reservoirs for which direct measurements are ossible. Most of the early studies on these relationships were made by the irrigation ineers of the United States Department of Agriculture in Colorado and California and fficients were developed for reducing pan records to lake evaporation.

poration at High Altitudes (1)

In 1946 studies of evaporation at high altitudes in lakes in the Sierra Nevada Mountains Fresno, California, were started by the U. S. Department of Agriculture in cooperation the Southern California Edison Company. These investigations were under the super-on of Harry F. Blaney for the government and William A. Lang and Leonard L. Longacre the company. Class A Weather Bureau Evaporation Stations equipped with Weather eau and Screen pans were installed at Shaver Lake (elev. 5,376 feet); Huntington Lake 6,954 ft.); Florence Lake (elev. 7,345 ft.); and Kaiser Pass (elev. 9,194 ft.) in the Upper Joaquin River Watershed. The water from these lakes, after being used several times developing electric power by the Southern California Edison Company, flows into a age reservoir created by Friant Dam built by the U. S. Bureau of Reclamation and is ilable for irrigation use by the farmers in the San Joaquin Valley. Evaporation from Class A Weather Bureau pan and temperatures have been measured by the Bureau of lamation at Friant (elev. 380 ft.) for many years.

The purpose of this investigation is to determine the monthly and annual evaporation ses from lakes at altitudes ranging from 4500 to 9200 ft. As indicated in table 1, asurements of pan evaporation during the winter months is not possible due to the freezing water in the pans at these high elevations. Thus, the problem of determining evaporation ring this period is rather difficult.

However, by correlating measured monthly evaporation (e) with mean monthly tem-atures (t) and percent of daytime hours (p) for a five-month period, June to October, at Huntington Lake, evaporation for other months may be estimated by Blaney as illustrated in table 2.

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(1) Evaporation from Free Water Surfaces at High Altitudes by Harry F. Blaney. esented at Amer. Soc. Civil Engineer Regional Meeting, Denver, Colo. September 1950.

TABLE 1

Monthly evaporation from pans at high altitudes, U. S. Weather Bureau Stations, Californi

Location	Elev. feet	Year	Evaporation, Weather Bureau pan, inches (1) (2)					
			May	June	July	Aug.	Sept.	Oct.
Shaver Lake	5376	1951	—	7.78	9.31	8.73	6.60	3.76
		1952	—	6.30 (3)	8.33	8.69	5.80	4.40
		1953	—	—	—	7.73	5.96	—
		1954	—	6.30	9.36	8.13	5.88	3.72
		Ave.	—	6.79	9.00	8.32	6.06	3.96
Huntington Lake	6954	1951	—	6.91	8.05	7.80	6.15	4.05 (3)
		1952	—	—	6.89 (3)	7.28	4.72 (3)	—
		1953	—	6.09 (3)	8.25	6.86	5.65	—
		1954	—	6.14	8.42	7.09	5.54	3.94
		Ave.	—	6.38	7.90	7.26	5.52	4.00
Florence Lake	7345	1951	—	7.46	8.54	8.13	7.05	4.90 (3
		1952	—	—	7.05 (3)	8.30	5.17	4.97 (3
		1953	—	—	8.04	8.15	6.19	4.87 (3
		1954	—	8.12	8.71	8.68	6.69	5.43 (3
		Ave.	—	7.79	8.09	8.32	6.28	5.04

(1) U. S. Agricultural Research Service in cooperation with Southern California Edison Company.

(2) Measurements discontinued in winter on account of water freezing in pans.

(3) One or more days estimated as average of measured period.

TABLE 2

Mean monthly observed and estimated evaporation from Weather Bureau pan and estimated lake evaporation, 1947-54, *Huntington Lake, California* (1)

Month	t	p	f	Evaporation, inches	
				Pan (e)	Lake (3)
June	51.5	9.89	5.09	6.67	4.67
July	60.8	10.05	6.11	8.18	5.73
August	58.3	9.44	5.50	7.33	5.13
September	56.5	8.37	4.73	5.61	3.93
October	48.0	7.82	3.75	3.62	2.53
November	40.4	6.87	2.77	2.1 (2)	1.46
December	32.6	6.72	2.19	1.1 (2)	.78
January	29.5	6.93	2.04	.9 (2)	.63
February	30.9	6.82	2.11	1.0 (2)	.71
March	30.0	8.35	2.51	1.7 (2)	1.19
April	38.8	8.87	3.44	3.2 (2)	2.24
May	44.6	9.87	4.40	5.1 (2)	3.56
Total				46.51	32.56

(1) Based on Blaney formula, $e = kf$ = monthly evaporation, inches; where
k = empirical coefficient,
t = Mean monthly temperature °F.
p = Monthly percent daytime hours.

$$f = \frac{t \times p}{100} = \text{Monthly use factor.}$$

(2) Estimated from curve.

(3) Reduction coefficient 0.07.

vaporation, Desert Areas

Silver Lake, Mojave Desert, Calif. (2). Silver Lake was formed within a period of three ays as a result of a flood in the Mojave River in March. Previously the lake had been dry or several years. Its maximum size was seven miles long and three miles wide. No inflow r outflow occurred during the study and the lake was entirely dry at the end of the following ear. Borings in the tight clay lake bottom indicated there were no losses by seepage. The urpose of the study was to determine coefficients for converting pan evaporation to lake vaporation and to develop an empirical relation between evaporation and meteorological actors, under desert conditions. Daily observations were made for about a year of temperature, humidity, wind movement, percipitation, and pan evaporation at a Class A Weather Bureau Evaporation Station and of changes in water level and temperatures of the lake.

Formation of the lake presented an excellent opportunity to study the relation of evaporation from a standard Weather Bureau evaporation pan to the evaporation from a shallow lake under the unusual conditions of lake bottom imperviousness, low rainfall and high desert temperatures. Of particular advantage was the absence of inflow, outflow or seepage, a condition resulting in evaporation being the sole means of water disposal.

The results show that annual evaporation from Silver Lake was 79 inches and that coefficient of 0.60 should be used in reducing Weather Bureau pan evaporation to lake vaporation in desert areas. Monthly coefficients by the Blaney evaporation formula $= k_c f(114 - h)$ = monthly evaporation in inches; (where k_c = monthly empirical oefficient, f = evaporation factor $= \frac{t \times p,}{100}$ where t = mean monthly temperature, f° and = monthly per cent of day time hours) were computed for desert conditions. The average k_c for the year was 0.0190.

Salt Sea, California (3) Salton Sea was formed as the result of a break of the Colorado River in 1905 when practically the entire flow of the river discharged into the Salton Basin or nearly two years. At that time this body of water covered about 350,000 acres and reached a maximum elevation of 195 ft. below sea level. For many years the excess of vaporation over inflow caused the elevation of the water surface to drop some 55 ft to minus 250 ft by 1923. Since 1935, the water level in Salton Sea has been rising.

In recent years this has resulted in encroachment and damage on adjoining lands, causing concern to Federal, State, and local agencies and land owners. Therefore, three vaporation stations bordering the sea were established to study the problem. An analysis of pan evaporation, gage heights, and inflow measurements indicates that the annual vaporation from Salton Sea ranges from about 70 to 76 inches. The Federal Government as withdrawn from entry all public land in the area below the elevation minus 220 feet. Salton Sea, in January, 1954, had risen to an elevation of minus 235.8 ft and thus has leeway f 15.8 feet before reaching the minus 220-ft contour.

Measurements of evaporation are being continued (1955-56) in cooperation with the mperial Irrigation District, Salton. By January 1955 the Salton Sea had risen to minus 35 ft. and by April 1956 to minus 234 feet. A review of this study and other reports indicates that the water surface will continue to rise for a number of years but will eventually stabilize elow an elevation of minus 220 ft. prior to the year 1980.

vaporation and Evapotranspiration, San Francisco Bay

Studies are being made by the Agricultural Research Service in cooperation with the Corps of Engineers and the California State Division of Water Resources to determine robable evaporation and evapotranspiration losses that would occur if barriers were onstructed across the San Francisco Bay to exclude salt water. This would create fresh-water ools to conserve water for irrigation, domestic, and industrial use.

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(2) Evaporation study at Silver Lake in the Mojave Desert, California, by Harry F. BLANEY, *Amer. Geo. Union*, 1956 (In press).

(3) Evaporation From and Stabilization of Salton Sea Water Surface, by Harry F. BLANEY. *Trans. Amer. Geo. Union*, Vol. 36, No. 4, August 1955.

In 1953-54 (4) available measurements of evaporation and consumptive use of water by vegetation were compiled and analyzed. New climatological stations were established in areas not covered by existing stations and measurements made on evaporation, temperature, humidity, wind movement and precipitation. Evaporation and consumptive use data were correlated with climatological records. Estimates were made of annual and monthly rates of evaporation from lake surfaces and consumptive use by marsh vegetation for the 1921-1952 period and for the five critical years, 1923, 1924, 1930, 1931, and 1951 by the formula, $u = kf$.

The time of occurrence and amounts of water losses from fresh-water barrier pools resulting from natural demands of evaporation and evapotranspiration by phreatophytes and hydrophytes growing in and adjacent to the barrier pools are important factors that must be considered in a water-balance inventory of the proposed project.

A survey of existing data revealed that evaporation measurements were being made from United States Weather Bureau type pans (four feet in diameter and ten inches deep) at fifteen locations in the San Francisco Bay and Sacramento-San Joaquin Delta area. Additional stations were established in areas not covered.

By the formula $u = kf$ the monthly use of water by marsh vegetation was computed for tules and saltgrass with the water table at one to five feet below the ground surface. Tables 3 and 4 illustrate some of the results.

TABLE 3

Computed average monthly evapotranspiration by saltgrass (with water table at 2 *feet) for San Francisco Bay and adjacent areas, Calif.* 192-52.

Month	Newark	Hamilton Field	Crockett	Antioch
	Inches	Inches	Inches	Inches
January	2.0	1.9	1.9	2.0
February	2.1	2.0	2.1	2.2
March	2.9	2.9	3.0	3.2
April	3.3	3.3	3.3	3.7
May	3.8	3.9	3.9	4.5
June	4.0	4.2	4.2	4.9
July	4.2	4.4	4.4	5.2
August	3.9	4.0	4.1	4.8
September	3.5	3.6	3.6	4.1
October	3.0	3.1	3.2	3.5
November	2.4	2.4	2.5	2.6
December	1.7	1.6	1.6	1.7
Mean annual	36.8	37.3	37.8	42.4

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(4) Evaporation and Evapotranspiration Investigations in the San Francisco Bay Area, by Harry F. BLANEY and Dean C. MUCKEL. *Trans. Amer. Geo. Union*, Vol. 36, No. 5, Oct. 1955.

TABLE 4

Computed mean annual evaporation from fresh-water lakes and evapotranspiration by marsh vegetation, 1921-1952, *at various locations in the San Francisco Bay area.*

Location	Water consumption, acre feet per acre				
	Lake evaporation	Evapotranspiration			
		Tules	Saltgrass *		
ewark	3.48	4.59	3.07	2.15	1.94
akland Airport	3.43	4.53	—	—	—
ears Point Road	3.85	4.48	—	—	—
amilton Field	3.55	4.67	3.11	2.16	1.94
rockett	3.59	4.73	3.16	2.20	1.98
ntioch	4.21	5.84	3.54	2.52	2.29
oice Island	4.05	5.67	—	—	—

* Columns 4, 5 and 6 are respectively for depth of two, three, and five feet to the water able.

METHODOLOGY OF EVAPORATION RESEARCH IN GERMANY PRESENT STATUS AND FUTURE TASKS

by

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Over a fairly long period of years an average portion of approximately 450 mm of the natural water supply through precipitation which amounts to 771 mm over the whole area of the Federal Republic of Germany, gets lost as a result of evaporation. This relatively high «loss» receives its particular significance—apart from its size— by the fact that it ranks high on the water balance sheet, inasmuch as from the water supply offered, first of all, the evaporation of soil and vegetation must be satisfied, whereas only the then still remaining portion is available for the surface runoff and the formation of ground-water. Evaporation thus ranks highest amongst the expense items on the water balance sheet. The effect of this predominant position is that evaporation may show rather high values even during years with low precipitation, and that its fluctuations from year to year are comparatively much less than those of precipitation. In the field of hydrology «evapotranspiration of a catchment» (évapotranspiration d'un bassin versant) is the most important of all the phenomena comprised by the term «evaporation». It is the key to the understanding of most of the hydrological occurrences. It is, therefore, the focal point of the research work regarding the water balance and it is appropriate to make it the starting point for all further discussions.

In spite of all progress accomplished regarding measuring technique, it has, as yet, unfortunately, not been possible to measure in a satisfactory manner the evaporation of the surface of catchment areas. True it is, that the evaporation of a natural water surface can be measured with the aid of evaporation pans, and that the evaporation of a small overgrown area can be ascertained by means of lysimeters. It is possible, too, to find out how much water the air can absorb under any given meteorological conditions, but it has not been possible up to now to measure the evaporation of a larger area with sufficient accuracy for any discretionary period, i.e. for one day, one month, or for any one single year.

When studying the extent of such area evaporation, it is appropriate to proceed from the water balance equation

(1) $$N = A + V + \Delta R.$$

In this equation N (Niederschlag) stands for precipitation, A (Abfluss) for the whole run-off, V (Verdunstung) for evaporation, and R for the change in the water reserves in the soil. Since for a catchment area only N and A can be measured directly, R, however, fluctuates considerably and, generally, cannot be disregarded, V cannot be determined by using the equation (1).

Suitable results are obtained only, if the research can be based on a period during which the water reserves in the soil are equally large at the beginning and at the end, so that R equals 0; or if it concerns a fairly long period of years, for which ΔR may be disregarded as against A and V.

(2) $$\Sigma N = \Sigma A + \Sigma V + \Delta R$$

$$\frac{\Sigma N}{n} = \frac{\Sigma A}{n} + \frac{\Sigma V}{n} + \frac{\Delta R}{n}$$

$$\bar{N} = \bar{A} + \bar{V} + \frac{\Delta R}{n}$$

$$\left(\frac{\Delta R}{n} \longrightarrow 0\right)$$

or $$\bar{V} = \bar{N} - \bar{A}.$$

This equation means that the average annual total of evaporation of a catchment area V) equals the difference between the corresponding longtime averages of precipitation (N) and run-off (A). In accordance with this procedure, frequently referred to as «the hydrological method», the area evaporation of a large number of catchment areas of different sizes and n all kinds of climates has been ascertained. At all discussions there should be no doubt about the fact that the average annual evaporation ascertained in this way is the only sure fact that is known about catchment evapotranspiration; even this, however, is true only on the condition that precipitation and run-off were ascertained with sufficient care and accuracy.

Since thus the average annual evaporation constitutes the starting point for all further studies regarding evaporation, the most important task, to begin with, consists in measuring the regional precipitation and run-off during many consecutive years in as many catchment areas of different size and character, as possible, and in deriving therefrom the average annual catchment evaporation. In Germany this has been done for some years with regard to more than 120 catchment areas by the hydrological authorities in cooperation with the German Meteorological Service (Deutscher Wetterdienst). It is intended to publish the characteristical values of the water balance in the German hydrological yearbook. The values concerning the average annual evaporation obtained in accordance with the «hydrological method» and thus based upon actual measurements can be regarded as a function of the average annual precipitation and of the average air temperature, and they can be illustrated by means of sets of curves. If only longtime mean values of precipitation and air temperature are known for a catchment area, then it is possible to ascertain with some degree of accuracy from such graphs, as they were prepared e.g. by WUNDT, COUTAGNE, and others, the corresponding average annual evaporation values and, incidentally, also the average annual run-off values. These relations must, however, on no condition be used for the purpose of calculating the evaporation and the run-off values from precipitation and air temperature for a *single* year or an even shorter period of time.

The solution of this important task is far more difficult. Methods using the water balance equation (1) as a starting point or proceeding from the average annual evaporation are the ones most likely to produce satisfactory results.

The water balance equation forms the basis of the «statistical method» by K. FISCHER. For the use of this method it is presupposed that the semi-annual runoff deviations from the average values are composed of constant portions of the same and of the preceding half-year,—that the average winter evaporation is in a constant relation to the mean summer evaporation, determined by lysimeter observations —and that the same ratio applies also to the apportionment of the evaporation shares of the precipitation deviations from the average values over the two half-years. This method has been applied to the Weser and Ems areas and has yielded plausible evaporation values for the individual years.

Abroad this method appears to be unknown.

Another method is based on the assumption that the evaporation of a catchment area from year to year is subject to about the same fluctuations as is the evaporation measured with weighable lysimeters. In practice, the procedure in this case is to distribute the longtime annual total of evaporation values obtained by means of the «hydrological method» over the individual years at the ratio of the lysimeter evaporation values. The reason why hitherto ittle use has been made of this method is the fact that there are not available, as yet, enough and suitable series of observations with lysimeters.

With regard to the value of lysimeter observations for hydrological research work opinions are divided. As to this question, the following can be said: measurements with weighable lysimeters will yield useful data regarding evaporation of overgrown soil on the following conditions: the lysimeters must be installed in an expert manner; i.e., the evaporating surface must be 1 squaremeter or more; the lysimeter contents must be monoliths (soil in situ), the surface overgrown; the depth of the lysimeter must be sufficient to allow free development of the roots of the plants; within the lysimeters the natural ground water evel must, if necessary, be copied. Attention must, however, be paid to the fact that, generally, a catchment area is not homogeneous as regards soil, orography, climate and vegetation, and that, to the contrary, conditions vary with the different locations. As a rule one can, therefore, expect to find values approximating reality only from a combination of observations of a fairly large number of lysimeters. At any rate, lysimeter measurings will give useful relative values, from which in connection with the average annual evaporation it will be possible to determine the fluctuations of the area evaporation from year to year.

On account of the high costs it will not be possible to install weighable lysimeters in all catchment areas. Instead, it will be necessary to limit oneself to the establishment of a few large-scale measuring stations, where evaporation can be studied with weighable lysimeters under all kinds of research conditions. In addition to weighable lysimeters non-weighable ones of equal dimensions but of more simple construction may furnish valuable informative data regarding the amount of percolating water and thus regarding ground water replenishment. Thanks to their low costs and simple operation it will not be difficult to install a large number of them throughout the whole country.

For the above-mentioned considerations, lysimeter observations are valued particularly highly in Germany. Several large-scale plants with weighable lysimeters have been established and, besides, work has also already been started on the installation of a fairly large number of non-weighable lysimeters. We give preference to lysimeter measurings, because we are of the opinion that in Germany, situated as she is in a transitional zone between maritime and continental climates with frequent soil-moisture-reducing droughts during the summer season, they lead to results which fit real evaporation far better than the measuring results obtained from evaporimeters of various types or from computations with formulae, taking into account only meteorological factors, but failing to take into account the effect of the variable moisture of the soil.

As already mentioned above, the water balance equation offers a possibility of calculating the evaporation of a catchment area, i.e., provided one succeeds in determining with sufficient accuracy the change in the water reserves. Unfortunately, this is possible in exceptional cases only. Apart from the rare cases, when the fluctuations of the water supplies take place above-ground to a large extent and are thus measurable (ice, snow, lakes), the problem, in general, is, to ascertain the fluctuations of the ground-water *as well as* of the water reserves in the soil above the ground-water level. In this upper zone relatively large reserves of water can be stored, particularly so, if the ground-water level is low, so that the fluctuations of the water reserves may be very considerable.

An additional aggravating factor is that the fluctuations of the water supplies in the upper zone but rarely run parallel to the fluctuations of the ground-water level. Only in exceptional cases will it, therefore, be possible to calculate from precipitation, run-off and changes in the water reserves, the evaporation of a catchment area for one single year or an even shorter period of time.

The correlations between precipitation and corresponding run-off are, as shown by COUTAGNE, far better for «water balance years», beginning on May first than for the customary water years, beginning on October or November first. The fluctuations of the water reserves in the soil from year to year are, due to the soaking during the winter season, far less pronounced in spring then they are at the end of autumn, and many facts seem to indicate that the differences between precipitation and run-off (N minus A) come very near to the evaporation for «water balance years». Whether it is advisable to let the «water balance year» begin on May first, April first, or even earlier, depends on the climatic properties of the catchment areas under examination and must be made the subject of a special investigation. Calculations regarding evaporation for German catchment areas in accordance with this method are being prepared. A discussion on the fundamental principles of this method during the General Meeting in Toronto is desirable.

If, thus, there are considerable difficulties as regards the determination of evaporation during a single year, it is well-high impossible to ascertain the evaporation of a catchment area during a single month. The best method still appears to be to ascertain first the evaporation values during the individual years by means of one of the methods described above and to derive therefrom the monthly values with the aid of lysimeter observations. We are justified in using this procedure, in view of the fact that the fluctuations of the catchment evapotranspiration from year to year are not only relatively small, but that, on the other hand, the yearly range of evaporation is remarkably constant.

As already indicated, the determination of catchment evapotranspiration by means of calculations or measurings proves to be so difficult, because type of soil, vegetation, climatic conditions, depth of ground-water level, and exposure to wind and radiation, vary extraordinarily much with the different locations, and because evaporation shows, in accordance therewith, great local differences. To this must be added, as already mentioned, that in our climate at the time of highest evaporation, i.e., during the summer season, dry periods occur at irregular intervals when the soil gets exceedingly dry and the actual evaporation remains far behind the so-called potential evapotranspiration.

Although the catchment evapotranspiration stands in the foreground of our interest, particularly with a view to the water balance, to the run-off phenomenon and to the run-off forecast, yet there are, aside from this, numerous cases, for which the knowledge of evaporation is also of great practical importance. We shall report on some of these cases forthwith :

The hydrologist is frequently faced with the task of having to provide the evaporation values for the supply area of ground-water-works. In most cases it will be possible to solve this problem with the aid of lysimeters, because it concerns mainly small areas with homogeneous soil-, vegetation-, and ground-water-conditions. A similar task may be involved, if it concerns the measuring of the evaporation of a permanently moist terrain, as, e.g., of a valley-meadow, having a high ground-water level. In this case the calculation of the so-called potential evapotranspiration (according to THORNTHWAITE) will be considered in addition to measuring of the evaporation with the aid of lysimeters, i.e., of lysimeters of a comparatively simple type of construction (Pot Lysimeters).

It is a known fact that there are all kinds of methods for measuring the evaporation of free-water surfaces. In Germany only series of observations with floating evaporation pans have been carried out up to now. The most serious of the disadvantages of these measurings is presumably the fact that the water contained in the evaporation pans will develop a daily range of temperature different from that of the surrounding free-water, and that the results are valid for one measuring point only. In these circumstances it appears to be risky to calculate evaporation of large water surfaces with the aid of coefficients from observations at one point. However, this difficulty may be overcome by measuring evaporation with the aid of several evaporation pans and by reducing the results to the temperature of the free-water surface. In the meantime, a new method has been developed in the United States of America, whereby evaporation is determined from the energy balance of natural water surfaces. It would be appreciated, if a report could be given in Toronto on the experiences gained in connection with the observations carried out at Lake HEFNER.

As important as the knowledge of evaporation from a snow cover is for the economic management of reservoirs, just as insufficient is our present knowledge of these losses. True it is that in the Bavarian Alps measurings were carried out with weighing devices especially developed for this purpose. Weather conditions, however, were so unfavourable that no clear picture could be obtained. Progress will only be made if through several winter seasons the water balance of the snow cover can be measured with the required accuracy by a research institute disposing of the appropriate equipment.

In conclusion, I wish to underline once again that regarding hydrological phenomena the main problem is the *actual* evaporation of the soil and of the vegetation, and that observations with the aid of evaporimeters are only conditionally useful. These latter devices by means of which evaporation is measured with larger or smaller water pans, or with moistened blotting-paper sheets (Piche) or with ceramic bodies, yield values only regarding the receptivity of the air for water. For hydrology, measurements with such devices mean nothing but auxiliary measurements, and it should be taken into consideration, whether it would not be recommendable to diminish such measurements considerably in favour of the hydrological methods and of observations with the aid of lysimeters.

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